PARAMETRIC CERs FOR REPLENISHMENT REPAIR PARTS
(Selected U.S. Army Helicopters and Combat Vehicles)

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PURPOSE

This research was undertaken by CALIBRE Systems, Inc. (CALIBRE) in support of the U.S. Army Cost and Economic Analysis Center (USACEAC). The objective was to assess the feasibility of developing cost estimating relationships (CERs) based on data from the Army Operating and Support Management Information System (OSMIS). The long-range objective is to develop methods to determine total operating and support (O&S) costs within life-cycle cost analysis.

The focus of this effort is on replenishment repair parts cost for selected U.S. Army air and ground systems. Replenishment repair parts are a key element in life-cycle cost, and after military personnel, they are one of the largest components of annual operating cost for a system. Six helicopters and five combat vehicles were selected for this analysis because their replenishment repair parts cost data were available for a large number of active duty divisions in all fiscal years of interest. Requests for a copy of data used in this analysis can be made to Mr. John Pulice, USACEAC, (202) 475-2138 or Autovon 335-2138.

BACKGROUND

Replenishment repair parts are individual parts, assemblies or subassemblies in Army Supply Class IX that are consumable (e.g., switch) or repairable (e.g., gunner's auxiliary sight) below depot level. These parts sustain end items of equipment after fielding. They resupply or replace initial repair parts stocks. This research does not include either initial or war reserves repair parts.

Repair parts costs in this study are based on wholesale requisitions collected from major supply points which fill unit (retail) orders and restock from Army inventories. Funding for the purchase of replenishment repair parts is the responsibility of each operating Major Army Command (MACOM) from the Army Operating and Maintenance (OMA) Appropriation.

Replenishment spares, which are funded by the Army Procurement Appropriation, are not included in this analysis. However, it must be noted that certain shifts in definition between replenishment repair parts and replenishment spares occur from year to year. That is, a certain item classified one year as a spare could be classified in another year as a repair part. All data used in this effort are based on Army classifications of repair parts and spares for FY 87.

This effort is related to the Visibility and Management of Operating and Support Costs (VAMOSC) initiative, which was intended to improve O&S cost estimates of new defense systems. It was also intended to provide critical maintenance and support information to promote cost-conscious design of new and fielded systems.

CALIBRE, under contract to USACEAC, manages OSMIS operation. OSMIS reports selected historical O&S data elements for major U.S. Army materiel systems.

DATA COLLECTION AND NORMALIZATION

The following total annual data by active duty U.S. Army division across four MACOMs for FY 84-87 were extracted from OSMIS:

- replenishment repair parts cost,
- mileage,
- flying hours, and
- density (quantity).

Normalization was required to adjust for an accounting system change and for inflation. Prior to FY 86, OSMIS data were based on shipments. Starting in FY 86, obligation data were collected. To adjust for the accounting change, cost data for FY 84-85 were increased by 30 percent. This factor was developed by comparing costs before and after the accounting system change (correcting for changes in density and activity). Then cost data were escalated to FY 88 constant dollars using the Operations and Maintenance Army (OMA) index.

METHODOLOGY

Number Cruncher Statistical System (NCSS) was used for this effort. Data were analyzed at two levels of detail. One level was an Army-wide perspective which was an aggregation of all division-level data for each system. These data were used to develop CERs related to the life-cycle cost of new systems which the Army might consider for acquisition. The second level consisted of division-level data. These data were used to develop CERs related to allocation of replenishment repair parts funding for systems already fielded. A separate analysis was performed for both new systems and fielded systems.

Army-wide totals by system were investigated for consistency and accuracy. There were several questions to resolve in dealing with these data. Are data consistent with intuition? How are data distributed? Are corrections of erroneous data needed? Are there outliers which should be removed? Is it reasonable to pool data across the four available fiscal years? Scatter plots, box plots, and a test of structural stability were used to provide answers to these questions.

After preliminary investigation of data, linear regression was used to develop CERs for replenishment repair parts. In addition to technical characteristics, dummy variables such as manufacturer were explored. Additionally, regression residuals were examined to ensure assumptions of the linear regression model had not been violated.

A wide variety of CERs were developed so that analysts can use whichever parameters are known at the time of the estimate. Many variables were examined; however, only relationships which seem intuitively reasonable were retained. Unless otherwise indicated, CERs shown are statistically significant (F test) at 99 percent confidence. CERs were developed using both simple and multiple regression. Both linear and log-log forms were evaluated. CERs were developed for both new systems (based on Army-wide data) and fielded systems (based on division-level data).

The following analysis is divided into two sections--one for helicopters and another for combat vehicles.

HELICOPTERS

The following helicopters were included in this research:

- OH-58A (KIOWA) observation helicopter,
- OH-58C (KIOWA) observation helicopter,
- AH-1S (COBRA) attack helicopter,
- UH-1H (IROQUOIS) utility helicopter,
- UH-60A (BLACK HAWK) utility helicopter, and
- CH-47D (CHINOOK) cargo transport helicopter.

As a perspective of helicopters selected for this analysis, Exhibit 1 represents each helicopter using a technique developed by Chernoff (1973). Chernoff Faces are multidimensional graphs in which facial features portray variables over the ranges shown. This seems an effective graphical technique, since people are naturally adept at discriminating among different faces. The six helicopters are grouped by mission. On the left, the lighter OH-58 observation helicopters work in tandem with AH-1S attack helicopters. On the right are light (UH-1H), medium (UH-60A), and heavy (CH-47D) lift helicopters.

For this example, we used only 6 of the 17 facial features NCSS allows. Darkness of the eyes represents the relative quantity of each helicopter in the active-duty Army inventory in FY 87. The UH-1H has the highest density. Nose width indicates relative weight, ranging from light observation helicopters to the heavyweight CH-47D. The more slanted the eyebrow, the faster the helicopter. The AH-1S is the fastest of the six. Ear height measures cost per flying hour in FY 87, showing the CH-47D as the most expensive to operate per flying hour. The length of the mouth indicates average monthly flying hours per helicopter in FY 87. For example, the OH-58A was flown fewer hours per month compared to its replacement, the OH-58C. The mouth opening coincides with fuel consumption. The CH-47D is clearly the largest fuel consumer.

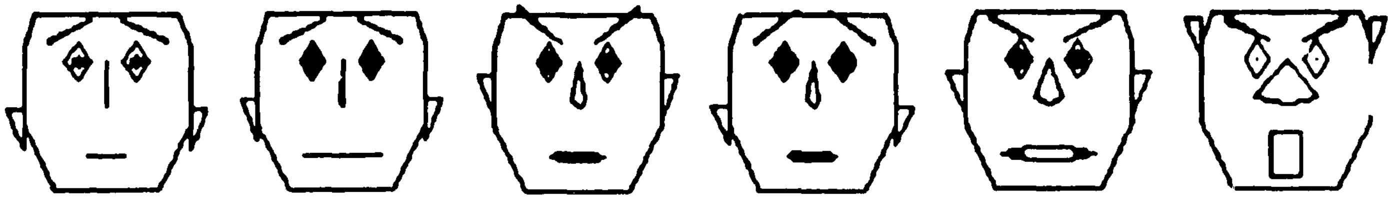
A wide variety of technical parameters were investigated as potential cost drivers for replenishment repair parts cost. A list of these parameters is given in Appendix A. Sources of data were:

- OSMIS,
- Jane's All the World's Aircraft,
- U.S. Military Aircraft Data Book,
- Standard Army Aircraft, and
- U.S. Army Aviation Planning Manual.

Data Analysis and CERs: New Systems (Helicopters)

Exhibit 2 is a summary of Army-wide data in terms of total annual flying hours and total replenishment repair parts cost by helicopter. Both flying hours and parts cost are plotted on the same axes for convenience; however, scaling factors differ. Flying hours are shown in ten thousands, and parts cost are shown in millions. For example, the first set of points for the OH-58A in FY 84 represents $6.4 million in parts cost and 79,327 flying hours. This chart indicates that OSMIS data seem to make sense over the four years studied. Opposite trends in flying hours reflect the phase-out of the OH-58A and phase-in of the OH-58C, mentioned earlier. The upward trend for AH-1S may be a sign of aging which increases costs. The UH-1H

CHERNOFF FACES: HELICOPTER PARAMETERS



OH-58A	OH-58C	AH-1S	UH-1H	UH-60A	CH-47D

FACIAL FEATURE	PARAMETER	RANGE
EYES (IRIS SIZE)	DENSITY	48 - 351
NOSE WIDTH	EMPTY WEIGHT	1464 - 22452 POUNDS
BROW SLANT	MAXIMUM SPEED	127 - 184 MPH
EAR HEIGHT	COST/FH (FY87)	$94 - $409
MOUTH LENGTH	OPTEMPO (FY87)	13 - 17 HOURS/MONTH
MOUTH OPENING	FUEL CONSUMPTION	27 - 400 GAL/HR

Exhibit 1

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FLYING HOURS AND PARTS COST
(HELICOPTERS)

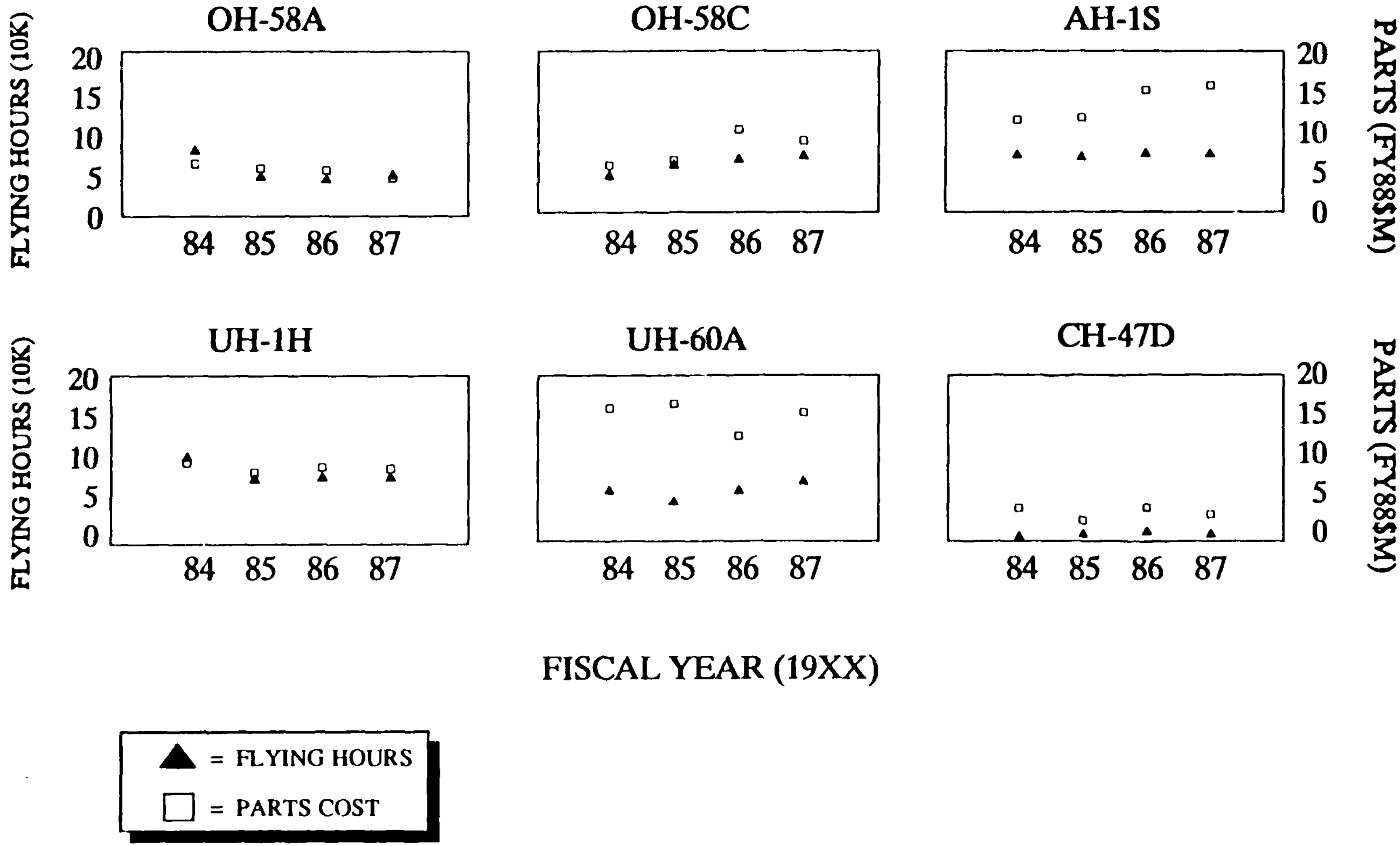

Exhibit 2

CALIBRE Systems

pattern seems stable. The UH-60A fleet was grounded for part of FY 85, but replenishment repair parts cost was incurred for deferred maintenance. However, fewer hours were flown, distorting the cost per flying hour. This accounts for the relatively large gap between flying hours and replenishment repair parts cost in that year. We understand there may have been a similar condition for the CH-47D in FY 84. Also, the relatively large gap between flying hours and parts cost for the CH-47D in FY 84 may indicate a newly fielded system which had not yet reached steady state. Conventionally, O&S cost estimation within life-cycle cost analysis is based on steady-state analysis; therefore, we decided to remove these two points (FY 85 UH-60A and FY 84 CH-47D) from further analysis.

For development of CERs, 22 observations were used: four years of data for six helicopters, less the two points removed. Both linear and logarithmic forms were employed. CERs for new systems were based on independent variables which drive Army-wide cost per flying hour. A summary of CERs is shown in Exhibit 3.

The strongest cost drivers in linear forms were those expected: weight, engine horsepower, fuel consumption, and fuel capacity. These variables have appeared in previous CER research of aircraft.

In the log-log set of equations, an interesting CER is the relation of cost per flying hour to approximately the square of maximum speed. This may be related to a theory of mechanics that drag increases by the square of speed. Another interesting finding is the relative weakness of maximum speed as a cost driver in this analysis. However, this fact is consistent with speed limitations for conventional helicopters. Gablehouse (1969) points out that:

> Since the lift on the blades on the advancing side cannot be permitted to exceed the lift on the retreating side, this factor tends to limit the top speed at which the fastest helicopters (with conventional rotor systems) can fly; for even the largest and most powerfully-engined of helicopters, at speeds just above 200 miles per hour the lifting and propelling characteristics of the rotor are affected, and a phenomenon termed "blade stall" is encountered.

Some multiple regression were investigated. Most combinations of independent variables were undesirable because they were highly correlated, and multicollinearity violates an assumption of the linear regression model. However, year of first production proved useful because it added explanatory power but was not highly correlated with other independent variables. Two CERs incorporating year of first production in conjunction with other variables are shown as examples of this form.

CER EQUATIONS (FY88$)

NEW HELICOPTER SYSTEMS

LINEAR FORMS	R^2 (ADJ)	PERCENT ERROR
COST/FH = 90.09 + .012 (EMPTY WEIGHT)	.86	19%
COST/FH = 101.50 + .035 (SHAFT HORSEPOWER)	.86	19%
COST/FH = 98.41 + .68 (FUEL CONSUMPTION)	.84	20%
COST/FH = 99.29 + .040 (FUEL CAPACITY)	.83	21%
COST/FH = 105.69 + .0053 (TAKEOFF WEIGHT)	.82	22%
COST/FH = 123.87 + .011 (PAYLOAD)	.76	25%
COST/FH = 85.44 + 53.77 (PRICE)	.70	27%
COST/FH = 70.64 + .011 (ENGINE RPM)	.49	36%

Exhibit 3

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CER EQUATIONS (FY88$)
NEW HELICOPTER SYSTEMS (CONTINUED)

LOG-LOG FORMS	R^2 (ADJ)	PERCENT ERROR
COST/FH = .00029 (CRUISE SPEED)$^{2.69}$	.75	26%
COST/FH = 2.56 (MAIN ROTOR HEIGHT)$^{1.67}$	.68	29%
COST/FH = 1.14 (OVERALL LENGTH)$^{1.24}$	.62	32%
COST/FH = .0014 (RATE OF CLIMB)$^{1.54}$	.62	33%
COST/FH = .0047 (MAXIMUM SPEED)$^{2.07}$	.61	33%
COST/FH = .14 (FUSELAGE LENGTH)$^{1.90}$	.57	35%
COST/FH = .0000049 (YEAR OF 1ST PRODUCTION)$^{4.01}$	.54	36%
COST/FH = .27 (MAIN ROTOR DIAMETER)$^{1.68}$	.52	37%
COST/FH = .15 (HOVERING CEILING OUT-OF-GROUND EFFECT)$^{.77}$	.45	40%

Exhibit 3 (Cont'd)

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CER EQUATIONS (FY88$)

NEW HELICOPTER SYSTEMS (CONTINUED)

MULTIVARIATE	R^2 (ADJ)	PERCENT ERROR
COST/FH = .00029 (FUEL CONSUMPTION)$^{.31}$ *(YEAR OF 1ST PRODUCTION)$^{2.75}$	.90	16%
COST/FH = .00015(EMPTY WEIGHT)$^{.30}$ *(YEAR OF 1ST PRODUCTION)$^{2.63}$	.88	17%
COST/FH = 229.64 - 95.44 (M1) + 132.61 (M2)	.81	22%

DUMMY VARIABLES M1 AND M2 REPRESENT AIRFRAME MANUFACTURERS: BELL (1,0); BOEING (0,1); SIKORSKY (0,0).

Exhibit 3 (Cont'd)

Several dummy variables were considered; however, only airframe manufacturer was a useful dummy variable in explaining cost per flying hour. Dummy variables for engine manufacturer, MACOM, and unit type were tested but did not prove significant cost drivers. It is not surprising that the smaller, lighter Bell Helicopters (AH-1S, OH-58A/C, and UH-1H) have a lower cost per flying hour than the Boeing CH-47D or the Sikorsky UH-60A. Dummy variables for manufacturer are, in essence, a substitute for weight, which already proved a strong cost driver.

In the course of regression analysis and analysis of variance, we used a statistical test usually attributed to Chow (1960) to determine whether or not data should be treated individually for each year or pooled over four fiscal years. Based on a test of all variables used in linear CERs at 95 percent confidence, we found the regression coefficient remained stable over the four years. Therefore, it was not unreasonable to pool data for all four fiscal years.

Once CERs were developed, the next step was to use them for prediction. As an example, Exhibit 4 shows a prediction for the LHX helicopter, which the Army is considering for acquisition. The prediction is based on the CER for empty weight as a driver of parts cost per flying hour. The regression line, 95 percent confidence interval (mean), and data points are shown. Based on the projected empty weight of 7,500 pounds, predicted cost per flying hour for the LHX is \$181 $\pm$ \$15. This estimate applies to the steady state (when cost per flying hour stabilizes some time after initial fielding).

Data Analysis and CERs: Fielded Systems (Helicopters)

Division-level data were investigated to develop CERs for fielded systems. After preliminary evaluation of the data, we decided to remove outliers conservatively. Using methods suggested by Chatterjee and Hadi (1986), outliers were identified using studentized residuals from regression of parts cost on density, flying hours, and empty weight. Studentized residuals are those scaled by the standard error based on a regression plane fitted to all other points. A calibration point or cutoff value of 2.5 was chosen for the absolute value of studentized residuals. This corresponds to a 99 percent confidence band for a t-distribution. Observations whose studentized residuals exceeded the cutoff value were considered outliers and removed. In this process, we removed 26 of 290 data points from analysis of fielded systems; no change was made to the data base for new systems.

Box plots (see Tukey, 1977) were used to provide some insight into division-level data. Exhibit 5 contains box plots of parts cost per flying hour and parts cost per helicopter for FY 84-87 by type of helicopter in order of increasing empty weight. The fact that these parts cost rates increase with weight reinforces the earlier finding that weight is a relevant cost driver.

CER APPLICATION: LHX PREDICTION

(95% CONFIDENCE LEVEL--MEAN)

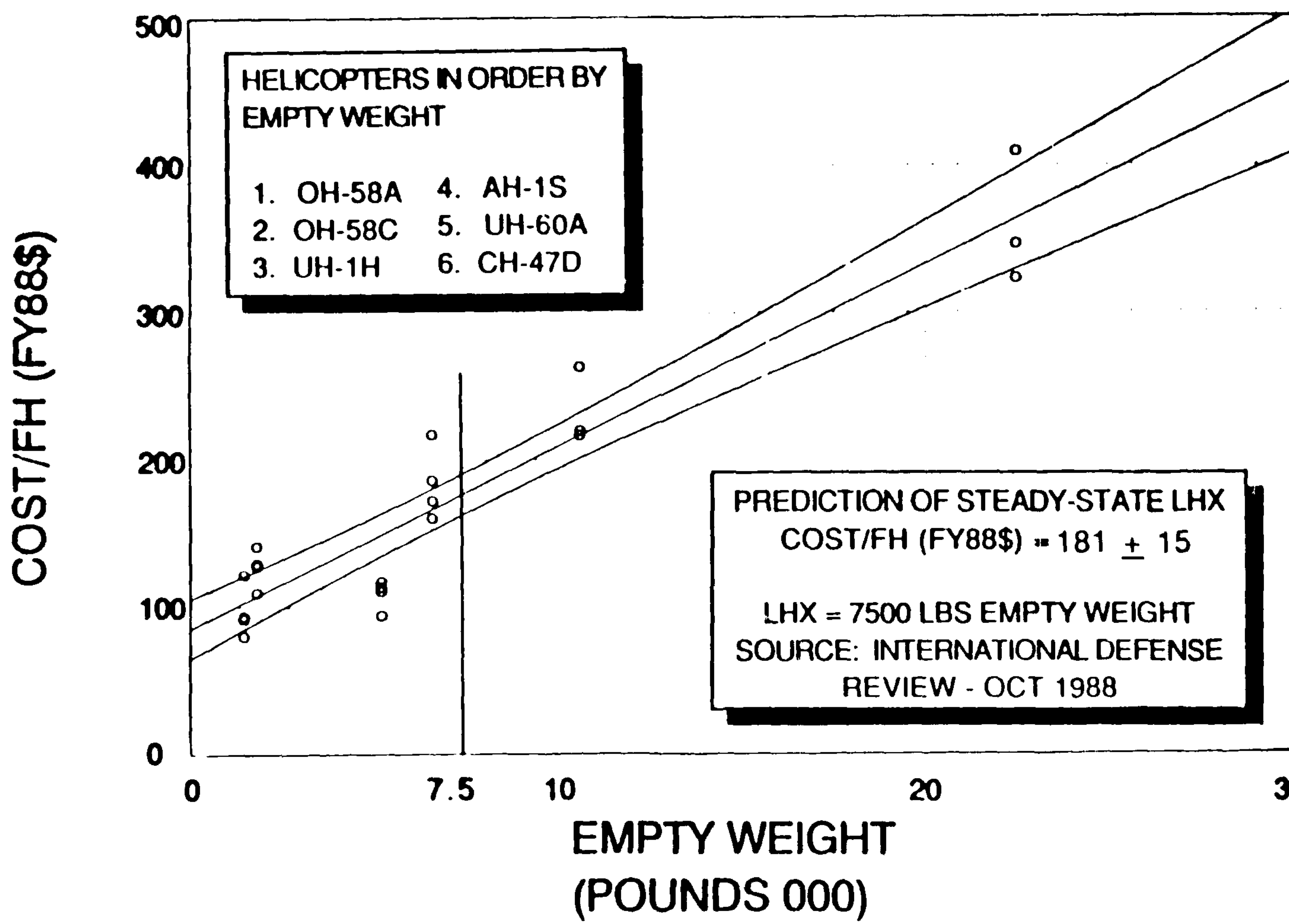


Exhibit 4

BOX PLOTS (HELICOPTERS)

COST PER FLYING HOUR

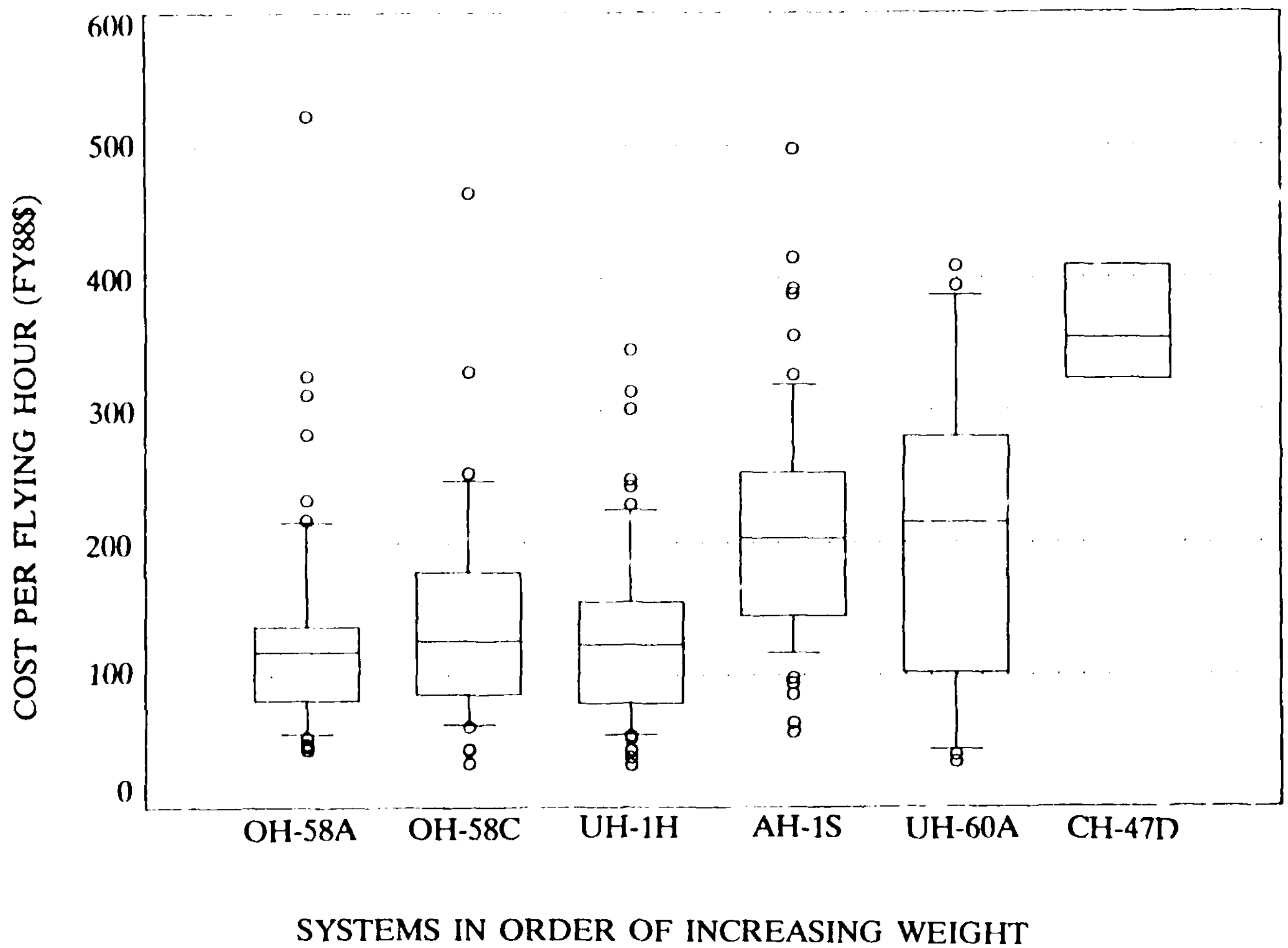


Exhibit 5

BOX PLOTS (HELICOPTERS) (CONT'D)

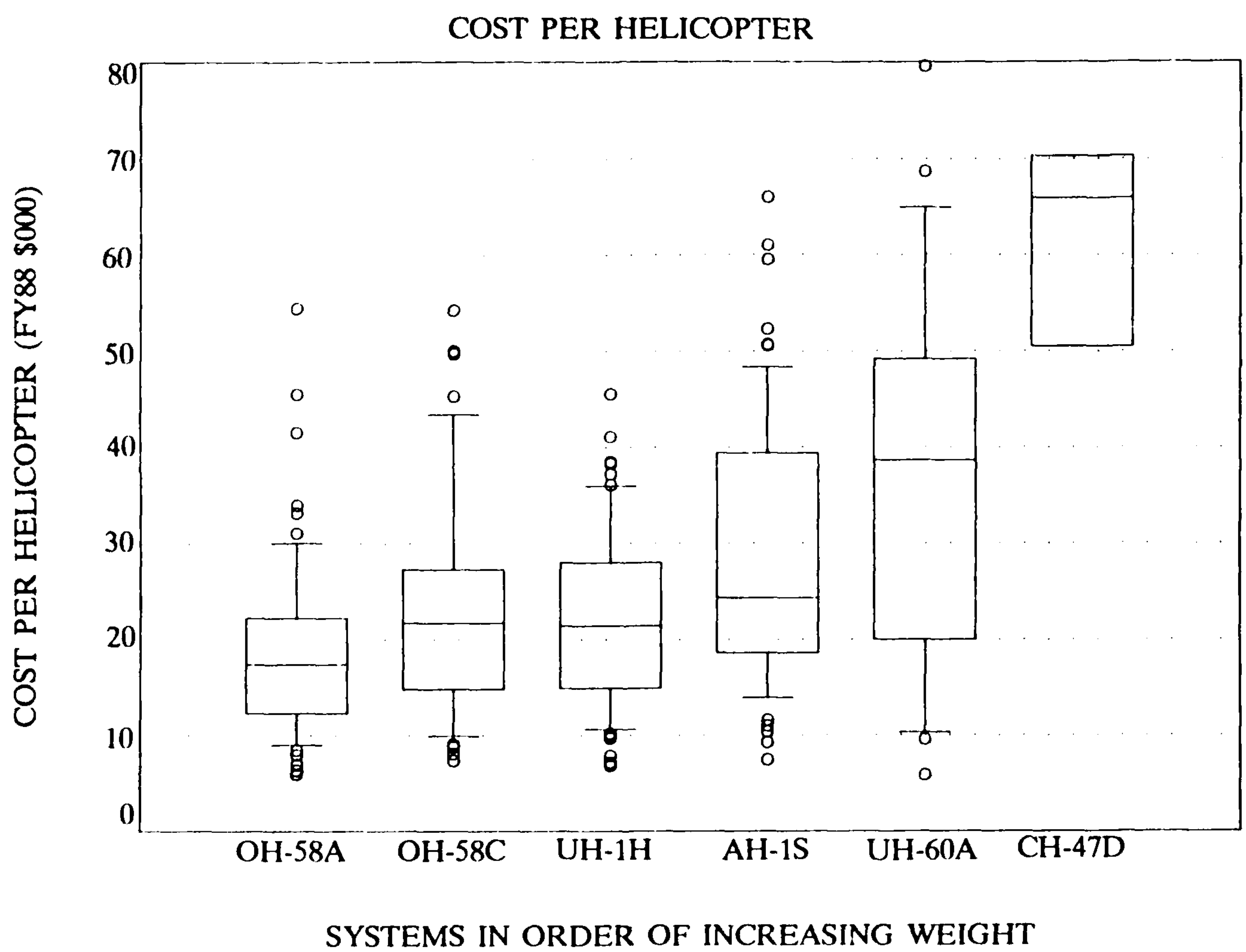


Exhibit 5 (Cont'd)

Each box contains data points for all units for FY 84-87. The midpoint of the box plot is the median of the data. For example, the median cost per flying hour for the AH-1S is approximately $200. The top and bottom of the box are boundaries for the middle half of the data. The whiskers (vertical lines emanating from the box) terminate at the 10th and 90th percentiles of the data. Values which appear beyond the whiskers are potential outliers, such as units with cost per helicopter above $30,000 for the OH-58A. In keeping with a conservative approach, we decided not to remove any more outliers.

Linear regression was used as a tool to develop CERs for fielded systems. As a first step, flying hours and density were examined as potential cost drivers. Based on previous results, we continued to pool data for all four fiscal years.

A summary of CERs is shown in Exhibit 6. CERs based on division-level data provided an unexpected result. We had expected flying hours to be strongly related to repair parts cost. Instead, we found that flying hours was not as strong as density as a cost predictor. Possible causes of this phenomenon are policy and fiscal limitations which affect flying hour allocations.

Useful rules of thumb emerged in terms of both cost per flying hour and cost per helicopter. In the first equation, the cost per flying hour for the average helicopter is $150. Based on the second equation, each helicopter adds approximately $21,000 in replenishment repair parts cost. These values are useful in the absence of more sophisticated methods. This situation can be improved by addition of a technical characteristic along with density. In the third equation, empty weight proves a useful addition to density. As an alternative to empty weight, use of dummy variables for airframe manufacturer (which are a substitute for weight) also improve the situation. The percent error for these CERs seem large, because there is more variability in dealing with data for individual divisions as opposed to Army-wide aggregates of these data.

COMBAT VEHICLES

The following combat vehicles were included in this research:

- M1 (Abrams) main battle tank,
- M60A3 main battle tank,
- M88A1 medium recovery vehicle,
- M2/M3 Bradley Fighting Vehicle, and
- M109A3 self-propelled howitzer.

CER EQUATIONS (FY88$M)

FIELDED HELICOPTER SYSTEMS

LOG-LOG FORMS	R^2(ADJ)	PERCENT ERROR
ANNUAL REPAIR PARTS COST = $.00015 \text{ (FLYING HOURS)}^{.99}$	.64	82%
ANNUAL REPAIR PARTS COST = $.021 \text{ (DENSITY)}^{1.0}$	.70	73%
ANNUAL REPAIR PARTS COST = $.0025 \text{ (DENSITY)}^{.97} {}^*\text{(EMPTY WEIGHT)}^{.28}$	.74	66%
DUMMY VARIABLE FORM		
ANNUAL REPAIR PARTS COST = .49 + .029 (DENSITY) - .66 (M1) + 1.25 (M2)	.72	53%

* DUMMY VARIABLES M1 AND M2 REPRESENT AIRFRAME MANUFACTURERS: BELL (1,0); BOEING (0,1); SIKORSKY (0,0).

Exhibit 6

As a perspective of combat vehicles selected for this analysis, Exhibit 7 represents each system as a Chernoff Face with features similar to those used for helicopters. The five combat vehicles are grouped by mission. On the left are heavy tanks and recovery vehicle. On the right are the Bradley Fighting Vehicle and a self-propelled howitzer. The M1 lies at the top of the range for most variables. For example, the high rate of fuel consumption for the M1 is well known. The M60A3 is slower (eyebrows) but cheaper to operate (ear height) than the M1. Because of its mission profile, we would expect optempo (mouth length) for the M88A1 to be low. The Bradley Fighting Vehicle and M109A3 are light vehicles (nose) which are relatively inexpensive to operate (ear height).

A list of technical parameters were investigated as potential cost drivers for replenishment repair parts cost are shown in Appendix B. The sources of these data were:

- OSMIS, and

- Jane's Armour and Artillery.

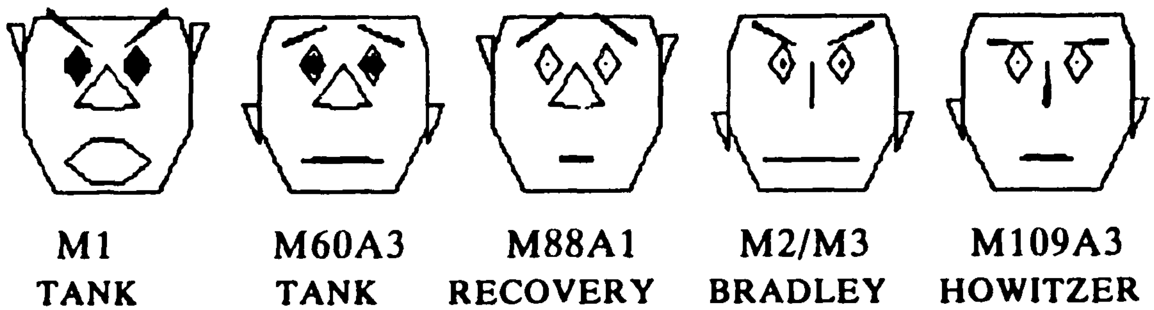
Data Analysis and CERs: New Systems (Combat Vehicles)

Exhibit 8 is a summary of Army-wide data in terms of total annual mileage and total replenishment repair parts cost by combat vehicle. Both mileage and parts cost are plotted on the same axes for convenience; however, scaling factors differ. Mileage is shown in hundred thousands, and parts cost are shown in millions. For example, the first set of points for the M1 tank in FY 84 represents $30.5 million in parts cost and 757,712 miles driven. This chart indicates that OSMIS data seem to make sense over the four years studied. The decrease in total parts cost for the M1 in FY85 is the result of a decrease in optempo. The increase in M1 cost and mileage starting in FY 86 results from an increase in systems fielded. The decreasing trend in M60A3 values reflect the replacement of this system with the M1A1 tank. The M88A1 values remain stable over the four years examined. The increasing trend in the Bradley Fighting Vehicle data is due to an increase in density for this system. The level for the M109A3 is fairly stable.

For development of CERs, 20 observations were used: four years of data for five combat vehicles. CERs were developed using simple and multiple linear regression. Both linear and logarithmic forms were employed. A summary of CERs is shown in Exhibit 9.

The strongest cost drivers in linear forms were engine horsepower and fuel capacity, as might be expected. Both equations have a zero intercept.

CHERNOFF FACES: COMBAT VEHICLE PARAMETERS



FACIAL FEATURE	PARAMETER	RANGE
EYES (IRIS SIZE)	DENSITY *	593 - 1293
NOSE WIDTH	COMBAT WEIGHT	25 - 60 TONS
BROW SLANT	MAXIMUM SPEED	26 - 45 MPH
EAR HEIGHT	COST/MILE (FY88) *	$15 - $33
MOUTH LENGTH	ANNUAL OPTEMPO *	651 - 910 MILES
MOUTH OPENING	FUEL CONSUMPTION	1 - 7 GAL/MILE

* FY87 SNAPSHOT

Exhibit 7

MILES AND PARTS COST
(COMBAT VEHICLES)

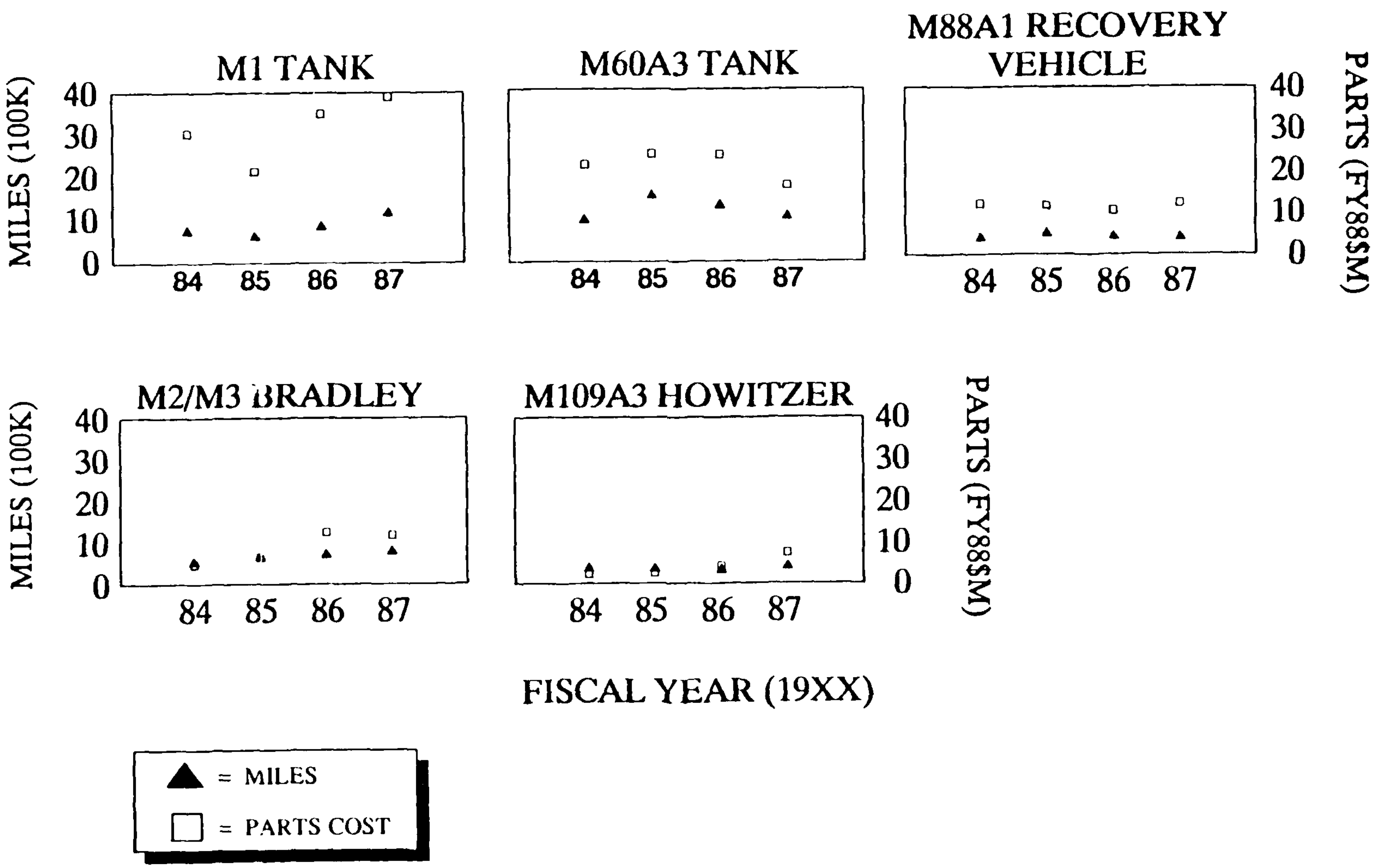


Exhibit 8

CALIBRE Systems

CER EQUATIONS (FY88$)

NEW COMBAT VEHICLE SYSTEMS

			R^2 (ADJ)	PERCENT ERROR
LINEAR FORMS				
COST/MILE	=	.026 (HORSEPOWER)	.85	18%
COST/MILE	=	.067 (FUEL CAPACITY)	.76	23%
LOG-LOG FORMS				
PARTS COST	=	$17\ (\text{DENSITY})^{1.4}\ (\text{KRPM})^{4.3}$	.90	29%
PARTS COST	=	$.00000012\ (\text{MILES})^{1.2}\ (\text{TRACK LENGTH})^{6.2}$	.88	31%
PARTS COST	=	$.0000000075\ (\text{MILES})^{1.5}\ (\text{HULL LENGTH})^{4.8}$	.87	34%
PARTS COST	=	$9700\ (\text{MILES})^{.54}\ (\text{WIDTH-10})^{.58}$	.83	40%

Exhibit 9

CALIBRE Systems

CER EQUATIONS (FY88$)

NEW COMBAT VEHICLE SYSTEMS (CONTINUED)

LOG-LOG FORMS			R^2 (ADJ)	PERCENT ERROR
PARTS COST	=	$44\ (\text{DENSITY})^{.99}\ (\text{TRENCH CLEARANCE})^{2.8}$	.82	40%
PARTS COST	=	$580\ (\text{DENSITY})^{1.3}$ * $(\text{VERTICAL OBSTACLE CLEARANCE})^{.96}$	.82	41%
PARTS COST	=	$8200\ (\text{DENSITY})^{1.0}\ (\text{FUEL CONSUMPTION})^{.55}$	.78	45%
PARTS COST	=	$45000\ (\text{DENSITY})^{.83}\ (\text{PRICE})^{1.5}$	.77	46%
PARTS COST	=	$6600\ (\text{DENSITY})^{.98}\ (\text{TRACK WIDTH})^{1.6}$	.75	49%
PARTS COST	=	$670\ (\text{DENSITY})^{.94}\ (\text{COMBAT WEIGHT})^{.96}$	.75	50%
PARTS COST	=	$.13\ (\text{MILES})^{1.4}\ (\text{HEIGHT-9})^{-.64}$	.75	50%
PARTS COST	=	$.000024\ (\text{MILES})^{.77}\ (\text{RANGE})^{3.0}$	.65	60%

Exhibit 9 (Cont'd)

CER EQUATIONS (FY88$)

NEW COMBAT VEHICLE SYSTEMS (CONCLUDED)

LOG-LOG FORMS	R^2 (ADJ)	PERCENT ERROR
PARTS COST = 12000 $(\text{MILES})^{1.8}$ $(\text{FIRST PRODUCTION})^{-5.1}$	.62	64%
PARTS COST = .012 $(\text{MILES})^{1.3}$ * $(\text{POWER-TO-WEIGHT RATIO})^{1.07}$	.63	63%
PARTS COST = 170 $(\text{DENSITY})^{1.4}$ $(\text{MAXIMUM SPEED})^{.45}$	.59	67%

Exhibit 9 (Cont'd)

Logarithmic forms for combat vehicles were developed somewhat differently from those in the helicopter section. Unlike helicopter data, both mileage and density appeared to have a nonlinear relationship with parts cost for combat vehicles. Therefore, instead of using a cost rate (such as cost per mile or cost per vehicle), parts cost was used as the response variable. In conjunction with density, engine speed (RPM) proved a particularly strong driver of parts cost. Track length proved strongest in conjunction with mileage. Another CER of interest involves price, which had a nonlinear relationship with parts cost. This does not agree with commonly held practice of determining parts cost as a straight percentage of price. The negative power in the CER based on height seems unusual. However, it is logical since heavy tanks built low to the ground are more expensive to operate than the relatively tall M109A3 howitzer.

In the course of regression analysis and analysis of variance, we used the Chow procedure to determine whether or not data should be treated individually for each year or pooled over four fiscal years. We tested CERs for both engine horsepower and fuel capacity; results were mixed. At 95 percent confidence, the CER for fuel capacity was stable over the four years, but the CER for engine horsepower was not. We decided to continue pooling data for all four fiscal years.

Once CERs were developed, the next step was prediction. As an example, Exhibit 10 shows a prediction for the Fire Support Team Vehicle (FISTV), a variant of the armored personnel carrier. The FISTV was only recently fielded, so it has not yet had time to reach steady state in operating cost. The prediction for the FISTV is based on the CER for engine horsepower as a driver of parts cost per mile. The regression line, 95 percent confidence interval (mean), and data points are shown. Based on the FISTV engine design of 215 horsepower, predicted cost per mile is \$6.6 $\pm$ \$3. This estimate applies to the steady state.

<u>Data Analysis and CERs: Fielded Systems (Combat Vehicles)</u>

Division-level data were investigated to develop CERs applicable to systems already fielded. As with helicopters, outliers were removed on the basis of studentized residuals. In this case, 5 outliers were removed, leaving 172 data points for this analysis.

Box plots were used to provide some insight into division-level data. Exhibit 11 contains box plots of parts cost per mile and parts cost per combat vehicle for FY 84-87 in order of increasing engine horsepower. The fact that these parts cost rates increase with engine horsepower reinforces the earlier finding that engine horsepower is a relevant cost driver.

Linear regression was used as a tool to develop CERs for fielded systems. In addition to technical parameters used for Army-wide analysis, mileage and density were examined as potential cost drivers.

CER APPLICATION: FISTV PREDICTION
(95% CONFIDENCE LEVEL--MEAN)

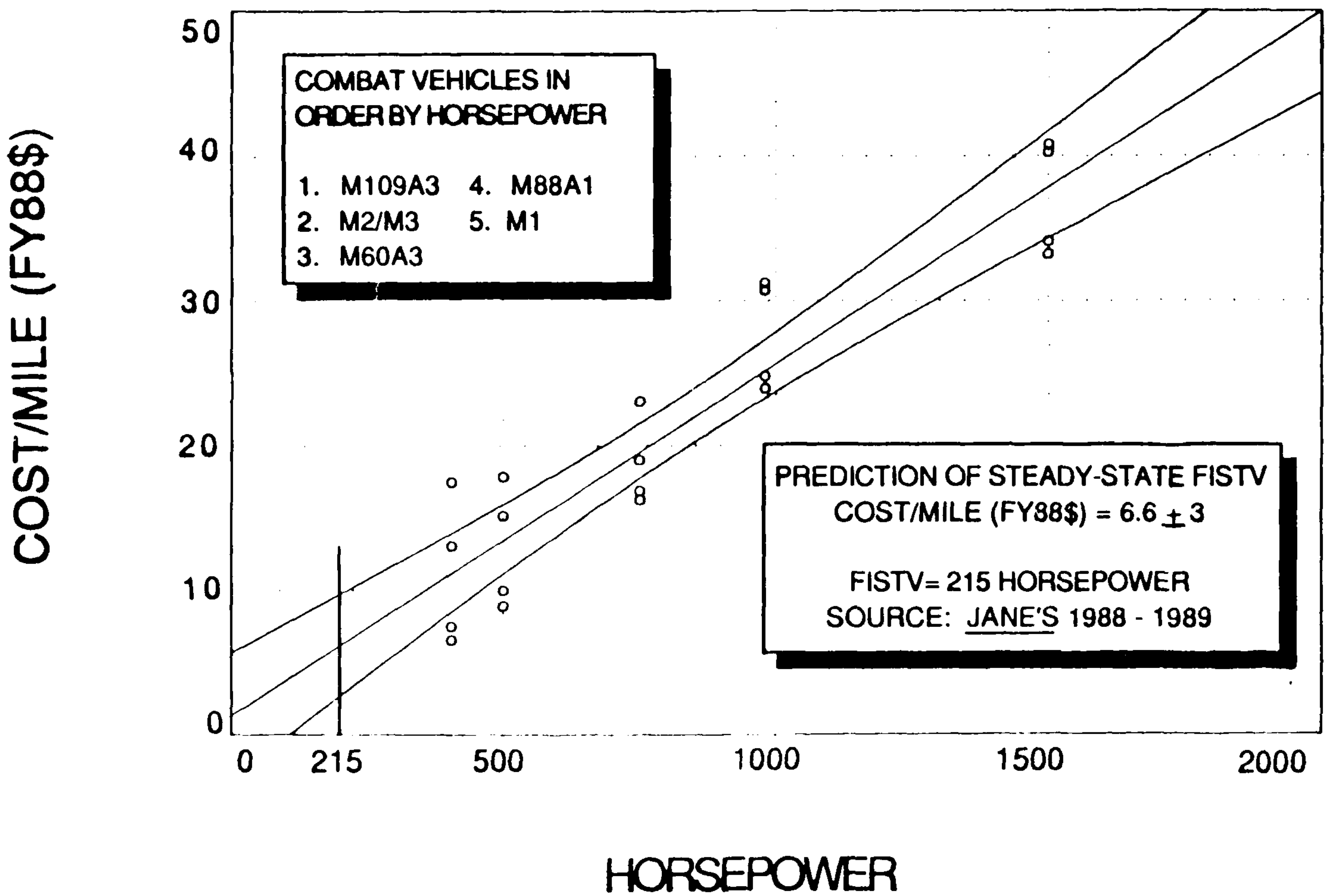


Exhibit 10

BOX PLOTS (COMBAT VEHICLES)

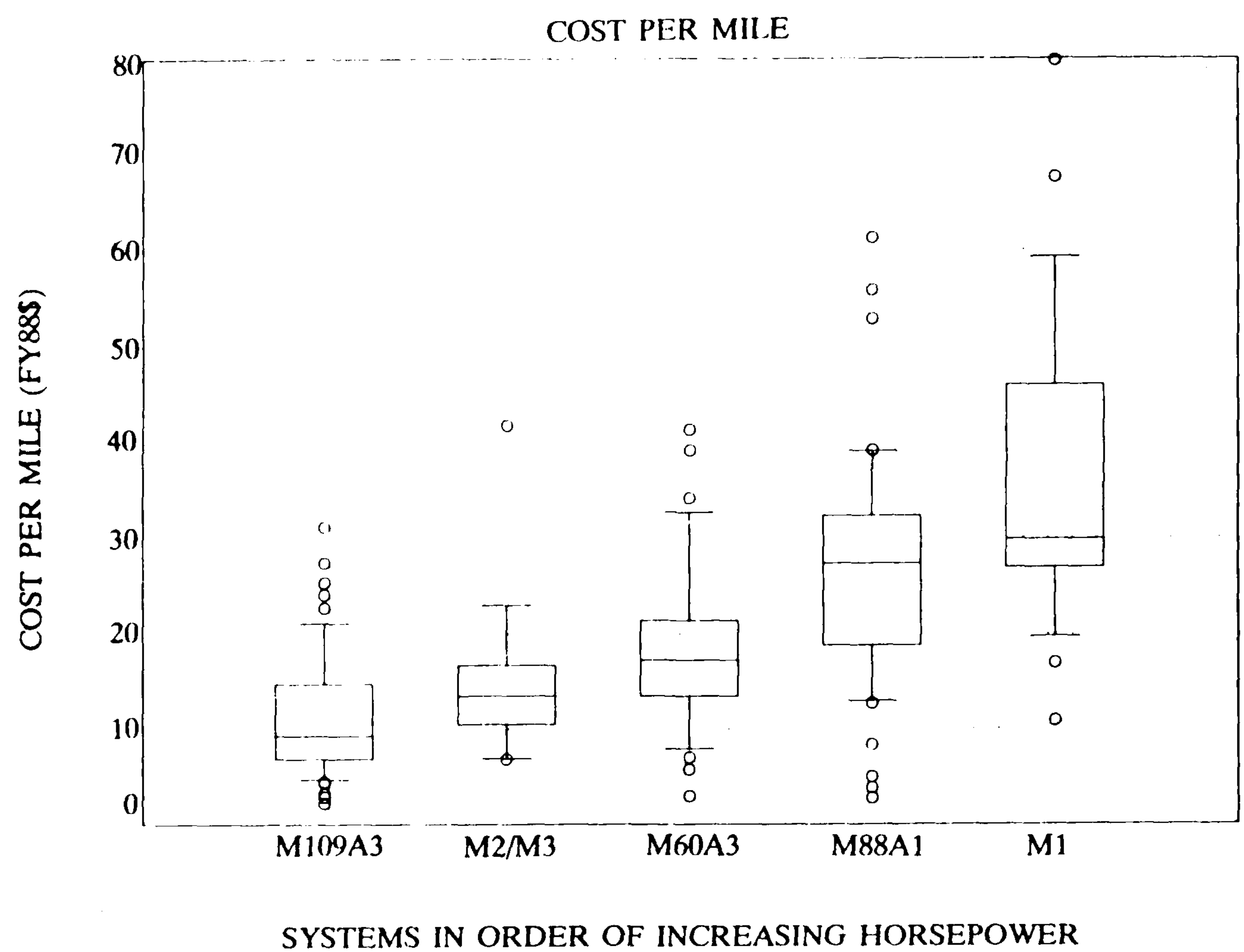


Exhibit 11

BOX PLOTS (COMBAT VEHICLES) (CONT'D)

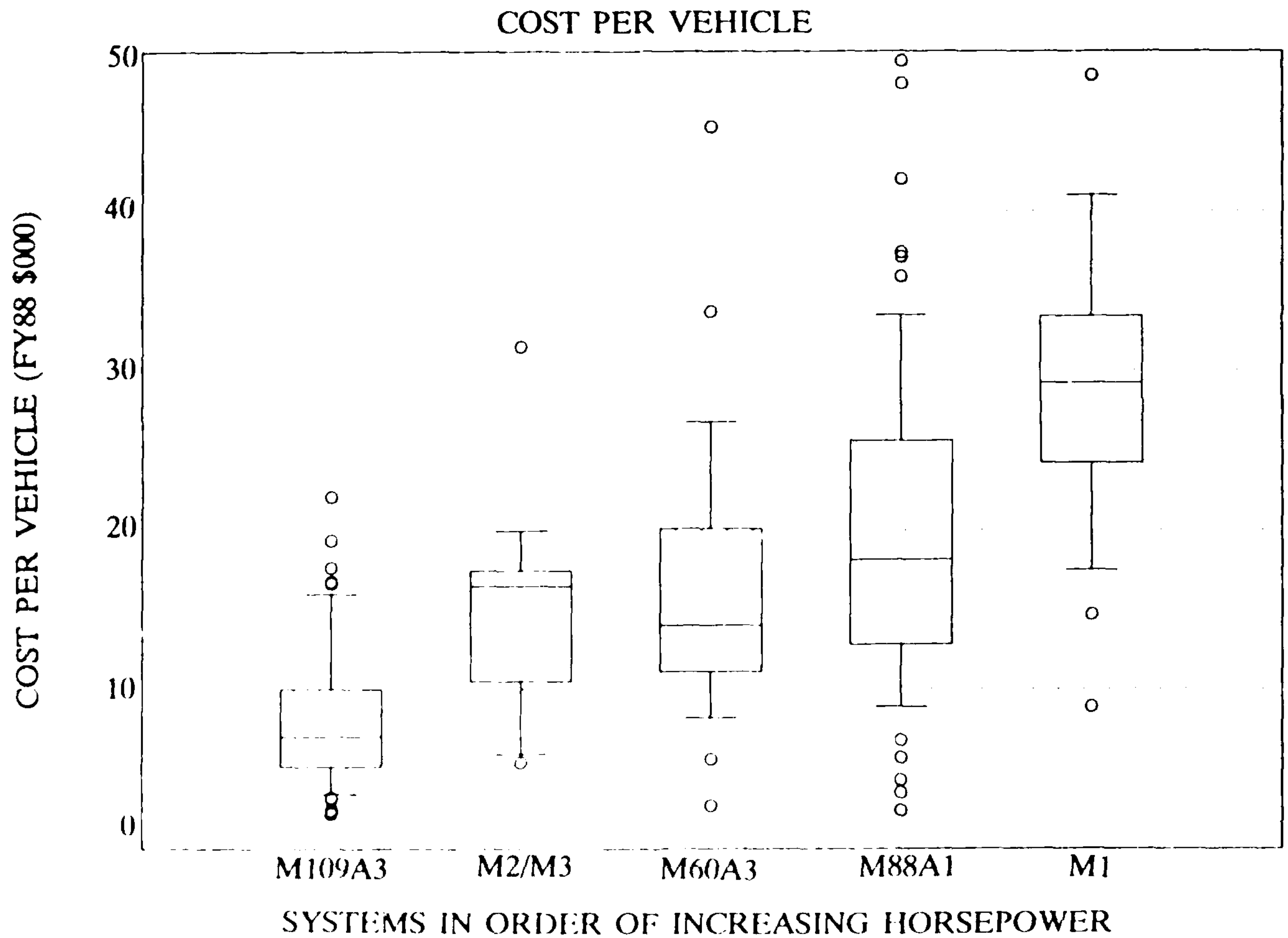


Exhibit 11 (Cont'd)

Useful CERs for replenishment repair parts based on both mileage and density. A summary of CERs is shown in Exhibit 12. Since record keeping for mileage is difficult, we had expected density to be a stronger cost driver than mileage. We were surprised to find the opposite was true. We found that CERs based on simple regression with mileage or density could be improved by addition of a technical characteristic. For example, engine horsepower proves a useful addition to density in explaining parts cost. Excellent results were obtained by adding power-to-weight ratio and fuel capacity to density.

RESEARCH BENEFITS

This research proved that OSMIS is an excellent source of data for development of CERs for both air and ground systems. While there is still room for improvement, the data were consistent and well behaved. OSMIS is mature data base ready to support increased analysis of U.S. Army O&S costs.

CERs developed in this research are statistically significant; they are also consistent with intuition. These models can be used to support Army decisions concerning costs of both new and fielded systems. Certainly this research is a beginning. There is certainly room for further investigation into every relationship developed here. These CERs should be tested continually against operational reality. Refinement and replacement of CERs should be a continuing research effort. USACEAC is already in the process of validating and extending this analysis.

This effort lays important groundwork for improved O&S analysis. Methodologies which were developed can be used to extend the analysis to additional fiscal years and additional systems. Furthermore, there is a potential to broaden this research into other O&S cost areas which OSMIS contains, such as depot maintenance, POL, and ammunition These procedures can support a complete O&S model.

This research is a landmark event for Army VAMOSC. It shows the OSMIS to be a source of believable, reliable O&S data. It proves the feasibility of using OSMIS data to develop useful tools for O&S cost estimating. It also shows USACEAC commitment to release of accurate, validated data under its VAMOSC charter.

CER EQUATIONS (FY88$)
FIELDED COMBAT VEHICLE SYSTEMS

LOG-LOG FORMS	R^2 (ADJ)	PERCENT ERROR
ANNUAL REPAIR PARTS COST = 7.5 $(\text{MILES})^{1.1}$	.81	86%
ANNUAL REPAIR PARTS COST = 7000 $(\text{DENSITY})^{1.2}$	.75	99%
ANNUAL REPAIR PARTS COST = .037 $(\text{MILES})^{1.0}$ * $(\text{HORSEPOWER})^{.87}$	.88	62%
ANNUAL REPAIR PARTS COST = 16 $(\text{DENSITY})^{1.1}$ * $(\text{POWER-TO-WEIGHT RATIO})^{.90}$ * $(\text{FUEL CAPACITY})^{.69}$	.91	27%

Exhibit 12

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APPENDIX A: VALUE OF TECHNICAL CHARACTERISTICS BY HELICOPTER

PHYSICAL PARAMETERS

	MAIN ROTOR DIAM (FT)	MAIN ROTOR HEIGHT (FT)	FUSELAGE LENGTH (FT)	OVERALL LENGTH (FT)	EMPTY WEIGHT (LBS)	PAYLOAD (LBS)	FUEL CAPACITY (LBS)
UH-60A	53.7	12.3	50.0	64.8	10624	8000	2198
OH-58C	35.3	9.5	32.6	41.0	1818	284	456
AH-1S	44.0	13.4	44.6	53.1	6598	1096	1795
UH-1H	48.0	11.8	41.9	57.8	5210	3880	1370
OH-58A	35.3	9.5	32.6	41.0	1464	170	455
CH-47D	60.0	18.7	51.0	99.0	22452	22000	6700

PERFORMANCE PARAMETERS

	MAX SPEED (MPH)	CRUISE SPEED (MPH)	HOVER CEILING* (FT)	CLIMB RATE (FT/MIN)	ENGINE POWER (HP)	FUEL CONSUM (GAL/HR)
UH-60A	184	167	10400	2460	3120	148
OH-58C	138	117	9700	1800	420	27
AH-1S	195	139	9900	1620	1800	98
UH-1H	127	127	4000	1600	1400	84
OH-58A	138	117	8800	1780	317	29
CH-47D	181	167	15000	3100	7500	400

* OUT OF GROUND EFFECT

OTHER PARAMETERS

	PRICE ($FY80)	YEAR OF 1ST PROD (19XX)
UH-60A	2.28	78
OH-58C	0.20	79
AH-1S	2.48	77
UH-1H	1.76	65
OH-58A	0.14	69
CH-47D	4.28	82

APPENDIX B: VALUE OF TECHNICAL CHARACTERISTICS BY COMBAT VEHICLE

PHYSICAL PARAMETERS

	COMBAT WEIGHT (TONS)	HULL LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)
M60A3	58.00	22.79	11.91	10.73
M1	60.12	25.98	11.98	9.47
M109A3	27.53	22.63	10.33	10.76
M88A1	56.00	27.12	11.25	10.58
M2/M3	24.67	21.16	10.50	9.75

	TRACK WIDTH (FT)	TRACK LENGTH (FT)	FUEL CAPACITY (GAL)
M60A3	2.33	13.89	375
M1	2.08	15.26	504
M109A3	1.25	13.00	135
M88A1	2.33	15.12	400
M2/M3	1.75	12.83	175

PERFORMANCE PARAMETERS

	MAX SPEED (MPH)	ROAD RANGE (MILES)	OBSTACLE CLEARANCE (FT)	TRENCH CLEARANCE (FT)
M60A3	30	298	3.00	8.50
M1	45	309	4.08	9.00
M109A3	35	220	1.74	6.00
M88A1	26	280	5.58	8.56
M2/M3	41	300	3.00	8.33

	ENGINE POWER (HP)	ENGINE SPEED (RPM)	FUEL CONSUM (GAL/MI)	POWER-WEIGHT RATIO (HP/TON)
M60A3	750	2400	1.90	12.93
M1	1500	3000	7.29	24.95
M109A3	405	2300	1.18	14.71
M88A1	980	2800	1.46	17.50
M2/M3	500	2600	1.12	20.27

OTHER PARAMETERS

	PRICE (FY89$)	YEAR OF 1ST PROD (19XX)
M60A3	1.183	80
M1	1.646	80
M109A3	0.758	78
M88A1	0.837	76
M2/M3	1.010	81

DEPARTMENT OF THE ARMY
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31 July 1989

Dr. Dan Nussbaum
Symposium Chairperson, XXIII ADODCAS
Crystal Gateway #4
Room 700
Naval Center for Cost Analysis
Washington, D.C. 20350-1100

Dear Dr. Nussbaum:

This letter constitutes our agreement to public release of Mr. Katz's paper, "Parametric CERs for Replenishment Repair Parts Cost," to be given at the 23rd Annual DoD Cost Analysis Symposium. This research was performed under contract to the U.S. Army Cost and Economic Analysis Center. If there are any questions, please call me at (703) 475-2138.

Sincerely,

For Judah Matthews
John L. Pulice
COTR